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ABSTRACT

The use of mind mapping (MM), a visual tool developed by T. Buzan (1983; 1996) to improve note-taking, foster creativity, organize thinking, and develop ideas and concepts, was studied in a sixth-grade classroom with 16 students as an instructional and learning tool. In MM, a central focus or graphic representation of the problem is placed in the center of the page, and key words, connected to the central focus with lines, are used to represent ideas. Students perceived MM as an entertaining and interesting approach and thought that MM enhanced their learning. Most students preferred individual MM; some preferred group MM. The teacher enjoyed using MM and thought that it fostered student motivation in learning science. Three appendixes contain a student-generated MM, a chart of goals and activities for the unit studied, and the survey and interview questions used with students. (Contains 35 references.) (SLD)

Student and Teacher Perceptions of Mind Mapping: A Middle School Case Study

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Introduction

Teachers and students use a wide array of visual tools in today's classroom for a variety of purposes. Often referred to as graphic organizers, visual tools is a term that has been adopted instead to reflect a broader conception of what constitutes graphic representations and their purposes (Hyerle, 1996). In this study, mind mapping (MM), a visual tool developed by Tony Buzan (1983, 1996) to improve note-taking, to foster creativity, to organize thinking, and to develop ideas and concepts, was explored in a grade six classroom as a pedagogical tool for enhancing science teaching and learning. The authors of this paper, Robin, a middle school science teacher, and Karen, a university researcher, worked collaboratively from September 2000 to June 2001 to: (1) explore the nature of MM as a pedagogical tool, (2) help grade six students develop the skill of MM, (3) implement MM in a variety of ways in a grade six science curriculum, and (4) ascertain students' perceptions of MM after using it as a learning tool for an extended period of time. This paper reports on how the MM was used as both an instructional and learning tool, on student perceptions of MM as a visual learning tool, and on teacher perceptions of MM as an instructional tool.

In using the MM technique, the authors adopted the guidelines for creating mind maps as outlined by the creator of the technique, Tony Buzan. These rules are summarized by Wycoff (1991, p. 43): A central focus or graphic representation of the problem is placed in the centre of a page; ideas are allowed to flow freely without judgement; key words are used to represent ideas; one key word is printed per line; key words are connected to the central focus with lines; colour is used to highlight and emphasize ideas; and images and symbols are used to highlight ideas and stimulate the mind to make connections. Appendix A provides an example of a student–generated mind map that was completed at the end of the study as part of a culminating assessment.

Mind Mapping and Student Learning

Visual tools include a wide range of graphic representations such as semantic webs, concept webs, Venn diagrams, flowcharts, and concept maps, to name a few. Often referred to collectively as graphic organizers, many of these diverse tools, according to Merkley and Jefferies (2001), derived from the research of David Ausubel (1960) in using advanced organizers or introductory prose passages to assist the reader in acquiring new knowledge. Later, advanced organizers became known as structured overviews, being adapted and modified to include visual displays of information that were used not only before instruction, but also during and after instruction (Barron, 1969; Earle, 1969). Eventually, "graphic organizer" replaced "structured overview" as the preferred term of usage.

Graphic organizers have been used for a variety of purposes to enhance learning. According to Readance, Bean, and Baldwin (1985), graphic organizers can be used to show cause-and-effect relationships, to compare and contrast ideas, to represent the chronological sequence of objects or events, to groups terms, and to answer problems or questions. Despite the plethora of organizers that exist, few have been studied systematically to determine their effectiveness and their role in teaching and learning (Dunston, 1992; Rice, 1994; Trowbridge & Wandersee,1998). Nevertheless, some categories of graphic organizers have been shown to support student learning in a variety of settings (Alvermann & Boothby, 1986; Guzzetti, Synder, & Glass, 1993; Sadoski, 1983). In the context of science education, concept mapping (Novak & Gowin, 1984) has been researched extensively over the last 20 years and has been shown to have many applications for science teaching, learning and research. In contrast, little research exists to describe how to best use mind maps, the graphic organizer explored in this study, to enhance teaching and learning. Even less research exists to explain how and under what circumstances mind maps should be used in the context of science teaching and learning.

Although the research base to support the adoption of MM as an effective pedagogical strategy does not currently exist, MM does seem to be consistent with several theories and approaches in education. Multiple intelligences theory (Gardner 1983, 1999), a pluralistic conception of intelligence that is posited on the existence of eight distinct intelligences (verbal-linguistic, logical-mathematical, visual-spatial, musical-rhythmic, bodily-kinesthetic, interpersonal, intrapersonal, and naturalist), provides a framework for teachers to examine and make decisions about many aspects of their instructional practice. According to Kagan and Kagan (1998), the theory can be used to match teaching styles to how students learn, to encourage students to develop all of the intelligences, and to celebrate student diversity. MM offers teachers a commonsense strategy that can be used to target the visual-spatial intelligence, thus providing another tool through which students can learn and show what they have learned. MM can also be used in conjunction with other teaching approaches that target other intelligences. For example, mind maps may be created by groups of students as they develop both academic and social skills through cooperative learning structures (Johnson & Johnson, 1990; Kagan, 1994; Sharan & Sharan, 1992). Another theory that has import for science teaching and learning is constructivism. In the constructivist view of knowledge, the individual constructs knowledge by interacting with objects and events through the senses (Tobin & Tippins,1993). In other words, individuals construct their own meaning and understanding of the world and knowledge through the interaction of what they know and believe and the ideas and experiences they encounter. There is an assumption that a reality exists but it is beyond the capability of humans to know that reality (von Glaserfeld, 1989). MM, if adopted as a learning tool individually or in groups, has the potential to provide a means for students to explore prior knowledge and understandings, to consolidate new learning with already held ideas and conceptions, and to reveal how new ideas are changed and adapted as new learning occurs. Mind maps can provide a visual record of student thinking and the development of student ideas, thus offering educators a concrete strategy for translating the theoretical underpinnings of constructivist theory into classroom practice.

The theory has had a significant impact on science education and is reflected in recent calls for educational reform (American Association for the Advancement of Science (AAAS) 1989, 1993; National Research Council, 1996). Current conceptions of scientific literacy, as conceptualized in the reform documents, require students to become familiar with the content knowledge of science and how to engage in scientific inquiry and problem-solving; to develop an understanding of the history and development of science and the nature and methods of science; and to acquire an understanding of the complex interplay amongst science, technology, society, and the environment. These calls for reform require new roles for both teachers and students. If students are to develop high levels of scientific literacy, then they will need to be afforded opportunities to learn in classrooms are that are premised on constructivist learning principles. "The attainment of a common goal of scientific literacy for a group of children with very different initial experiences and very different capabilities . . . [is] not . . . easy. It . . . require[s] a variety of learning routes and learning experiences (Hodson & Reid, 1988, p. 660). Students need opportunities to experience learning and assessment in a variety of ways that consider students' individual learning needs, interests, abilities, and backgrounds.

Research Design

This interpretative case study (Merriam, 1998; Stake, 1994) focuses on the perceptions of 15 students, a grade six class, after developing the skill of MM and using it in a variety of ways as they participated in an on-line curriculum unit called *Blue Ice* (see the description below). In addition, the study reveals Robin's perception of MM and her reflections on her role as a teacher researcher. The authors, Robin and Karen, approached the study as a collaborative inquiry; they were both researchers and full participants in the research. They participated equally in all aspects of the project, "shaping the [research] question, designing the inquiry process, and participating in the experience of exploring the inquiry questions, making and communicating meaning" (Bray, Lee, Smith, Yorks, 2000). Through co-inquiry, they were able to develop a greater understanding of the nature of mind mapping and to ascertain students' perceptions of mind mapping as a learning tool. Robin and Karen met on a regular basis to engage in planning, action, and reflection as the study proceeded. Ongoing cycles of action and reflection informed their planning, and helped them monitor and interpret the unfolding research. Questions that guided the research included: 1) How can MM be used as both an instruction and assessment tool in science? 2) How long will it take for grade six students to become competent mind mappers? 3) How will students feel about using MM as a learning tool? 4) How will MM enhance students' motivation in science? and 5) How will MM assist students in learning science?

The collaborators. Karen, an experienced educator of 15 years, had been a high school science teacher for the first five years of her teaching career. She later worked as a school district consultant in gifted education for several years before pursuing higher studies and becoming a teacher educator and educational researcher. Some of her research interests include teacher development, instruction in K-8 science and technology, and action technologies. As a proficient mind mapper and a former K-12 teacher who had used MM successfully as an instructional tool, Karen looked forward to working with a middle school science teacher who shared her interest in MM.

An educator for the past 30 years, Robin started the profession through the provision of home schooling for her children. Eventually, Robin returned to higher education and later received dual New York State Certification in 1990: N-6, General Science 7- 9; Biology, General Science 7 -12. Over the past decade, Robin has been a frequent presenter at New York State Science Teachers' Association conferences, has written for local and national science journals, and generally has taken advantage of every opportunity to combine the role of middle school science teacher and teacher-researcher. She accepted a lower middle school science position at her present school in 1987 and has taught there since that date.

One of the benefits, according to Robin, of teaching at a small progressive independent school is "the curricular freedom inherent in the position. One of the disadvantages is the limited opportunity to share ideas with other educators." She was the only science teacher for students in grades 5 and 6. Moreover, it was very difficult for her to find peers with whom to share ideas and to reflect on the larger issues, such the underlying philosophies behind curricular decisions. As a result, Robin has always looked for connections with university-based educators as a means of keeping current with research related to her field. Thus, it was the desire for personal growth and challenge that led her into her current partnership with Karen.

Robin and Karen met informally in a social context. Because of Karen's strong research interest in teacher development and science instruction and Robin's desire to expand her instructional repertoire and to work collaboratively with another science educator, they decided to forge a partnership. After several discussions, Robin and Karen decided to pursue MM as a focus for their work. "Helping students bridge the gulf between hands-on activities and science concepts has consistently been one of the most difficult aspects of [her] job" (Robin). Combining visual, creative appeal through colour, symbols, and graphics, while encouraging students to construct their own understanding through organizing information seemed to have potential for fostering student motivation and higher levels of thinking. The research literature about the efficacy of MM as both a teaching and learning tool in the context of K-12 education is scant; thus, Robin and Karen viewed this study as exploratory in nature.

The school context Pinegrove School (pseudonym) is a small K-12 independent school that provides an informal learning environment where students are very comfortable sharing personal as well as academic information with the teachers. The upper school students have few required responsibilities outside of academic classes and during free times students may frequently be found socializing or studying on the floor in the hallways. However, the curriculum is quite demanding and post-secondary education of some kind is chosen by almost 100% of the student population.

The lower school, grades K-4, operates from a child-centred approach without formal tracking in any subject. The middle school introduces tracking for math classes in grade 6, but this does not affect science which is untracked until the upper school. The population was largely suburban, with a 10-15% minority population at any given grade level. Approximately 40 % of the students receive some kind of financial aid. Located in an area with excellent public schools, few students attend Pinegrove School for more than four to six years. In any class of sixteen, there are usually two to four students receiving resource room help for learning disabilities that range from organizational/attention problems to severe analytical or linguistic impediments.

All middle school science classes are heterogeneous in terms of student ability with a deliberate effort made only to balance males versus females and active versus passive learners in a manner that ensures the greatest success for all. During this study, Robin taught four groups, two grade 5 and two grade 6 classes. Although Robin was required by the science department to teach basic science process skills embedded in a very general science curriculum, she had considerable freedom in designing and implementing her science curriculum.

Robin and Karen elected to work with one grade six class having seven males and nine females. (One student chose not to participate in the study; thus, data was not collected from this student.) This decision was made for the practical reason of Karen's availability to make classroom visits. However, both grade 6 classes followed the same curriculum and were introduced to mind mapping as a learning strategy. Most of the students in the grade six research group had attended the school in grade five. They were accustomed to teamwork where the major form of assessment was the work in progress and the final product. Formal paper-and-pencil testing was not the norm in science at this grade level. When it was employed, it was used primarily to assess content understanding.

In the school's eight-day cycle, the class met for science every other day, usually in the morning. Each class was 90 minutes, with two exceptions. One class period in the cycle was 45 minutes in duration and on another day, students attended a 90-minute period in the morning and an additional 45-minute period in the afternoon.

Methods. The study occurred over a 10-month period from September 2000 to June 2001. To establish the trustworthiness and credibility of the study (Guba, 1981), several data sources and data collection methods were used, including:

1. Semi-structured interviews

At the end of the study, each student participated in a 20-30 minute semi-structured interview that explored his/her understanding of MM as a learning tool. Adopting the semi-structured format allowed Robin and Karen to explore predetermined topics, while giving the students some freedom to elaborate on their ideas. The interviews were audiotaped and later transcribed; careful notes were taken after each interview.

2. Fieldnotes

Observation can often reveal insights about a group that would be difficult to ascertain from other methods (Bell, 2000). Karen, the university researcher, visited the students' classroom at least three times per week for instructional periods lasting 40-80 minutes. During these visits, she was a participant-observer, acting as a resource, working with small groups of students, and co-teaching with Robin, the middle school teacher. Karen took copious notes both while observing and shortly after the observation period. Robin also kept observational notes; both sets of data served as a means to crosscheck what had been observed and to corroborate interpretations of the data.

3. Open-ended questionnaire

At the end of the study, students were asked to respond, in writing, to eight open-ended questions about their understanding and perceptions of MM. These questions were also used as part of the interview schedule of questions. In this way, students had opportunities to elaborate on their written responses and the researchers could compare different types of data for the convergence of themes.

4. Documents

Student-generated documents (samples of writing, mind maps, models and other products) provided another means to ensure triangulation. In addition, lesson plans and other materials produced by Robin became sources of data, enriching analysis and interpretation.

Data analysis and interpretation began very early in the study. Most of the data were in the form of free-flowing texts (Ryan and Bernard, 2000). Several levels of data analysis were used, from the most fundamental of assigning tags to short blocks of text to the establishment of categories and then broader themes. The researchers became 'grounded' in the data (Strauss, 1987) as they identified concepts and developed themes. Some themes emerged from the data, while others reflected themes established prior to the commencement of the study.

Outcomes and Discussion

An on-line interactive program, *Blue Ice*, specifically created for middle school students by On-line Class (2000), provided a context for the study. The program is organized into 8 units having two distinct threads–food webs and weather/climate change–that may be mixed or matched to meet the needs of individual classrooms. The program's primary learning goals are to help students develop an understanding of the interrelationship between animals and their environment, the basic requirements of habitats, and the impact of human activity on ecosystems. Robin and Karen elected to follow the food web thread and extend it over a two-month period. Several on-line components (background resources for the unit, sharing ideas with other schools, and ask-a-scientist) were part of the unit; however, most of the learning activities occurred off-line. Refer to Appendix B for a synopsis of the learning activities that were part of the unit.

Applications of the MM tool to practice. Initial explorations of the MM strategy by Robin and Karen involved considerable reading about all forms of graphic organizers and their uses, followed by more focussed reading about MM. Karen had used the tool previously; however, it was not until Robin began to create her own maps and use them in the classroom that she became comfortable with the tool. This is referenced in Robin's comments: "Initially I had some trouble differentiating between concept mapping and mind mapping. However, it was not until I began to experiment with making mind maps for instructional purposes that it became a comfortable tool" (Personal reflection, May 6, 2001).

The students in this study had not used mind mapping in former classes. Consequently, Robin and Karen provided considerable time and support to assist students in mastering the mind mapping technique. As an introduction, Robin and Karen provided students with a global overview of mind mapping by presenting them with a mind map about mind mapping. After explaining the general rationale for using this technique, students brainstormed ideas to include in a mind map about their school. As they brainstormed, the authors created a mind map on the board with coloured chalk. After this global introduction, the authors decided to focus on symbols and incorporate the use of symbols into instruction before having students create their own mind maps. Later in the Fall term, students were asked to periodically complete teacher-generated maps prior to instruction and sometimes during or after an instructional sequence. Initially, some students struggled with representing their ideas and concepts with a key word, wanting instead to convey their thinking through short phrases and sentences. As they developed the skill of mind mapping, the longer phrases disappeared to be replaced with a word or two to represent a concept or idea. By early January, the authors felt the students were ready to incorporate the mind mapping technique into the *Blue Ice* unit.

Throughout the unit, the MM strategy was used to introduce new topics through teacher-generated maps created prior to instruction or during instruction. MM was used as a formative tool to assess students' ongoing development of ideas and concepts as they generated individual and group maps. One piece of summative assessment involved the individual creation of an open-ended mind map that illustrated the relationships amongst concepts studied in the unit. Students were provided with a rubric for grading purposes prior to this in-class assignment. One of the large focussing activities completed during the unit was the creation of a very large class mind map (5' x12') to reveal students' understanding of the characteristics of Antarctica animals, food chains and webs, and the nature of the Antarctica environment. Students were organized into teams of three or four, with each being responsible for researching information on two organisms from the Antarctic food web and constructing parts of the overall class mind map. The large visual display provided a backdrop for students to discuss and reflect upon their developing ideas. A final application of mind mapping was to offer students choice in the completion of assignments. Often, they used a traditional format such as an essay, while in other instances they opted for cartoons, models, or mind maps.

Student perceptions of mind mapping. In ascertaining students' perceptions of MM after using it over a six-month period, four distinct themes emerged from the data. Students perceived MM as a fun, interesting, and motivating approach to learning; students conceptualized MM as having a variety of purposes in learning science; students expressed preferences in terms of individual versus group mind mapping; and the majority of students reported that MM enhanced their learning in a variety of ways. Although the themes emerged primarily from data collected through student surveys and interviews, themes were also corroborated using data collected through classroom observation and the assessment of student work. Appendix C includes both survey items and interview questions used in exploring students' perceptions of MM.

When given the survey statement "I enjoy creating mind maps," 10 of the 15 students either strongly agreed or agreed with the statement, while five students disagreed with the statement. During the interviews, many of the students reported that MM was a fun and interesting way to learn science. This is evidenced in comments such as "It was fun and easy to understand," "It was fun because we got to draw and we did not have to write lengthy reports," "Yes, it was more interesting than usual." Several students, at least 60%, attributed the fun aspect of MM to the opportunity to be creative when constructing the mind maps (choice in colour, symbols, key words, and design).

Closely linked to affective types of outcomes are cognitive learning. When given the statements, "Mind mapping helps me understand concepts and ideas in science," 12 out of 15 responded with agree or strongly agree with the statement. In responding to a more focussed statement about learning in the *Blue Ice* unit, "Creation of a class mind map helped me understand the relationship between the animal I researched and its environment," all students, with the exception of one, strongly agreed or agreed with this statement. In the open-ended survey questions and during interviews, students identified a range of ways that MM helped them in learning science: increased attention, better organized thinking and ideas, improved memory, deeper understanding, better approach for sharing ideas during assessment, and improved note-taking. The following are some of the students' comments about how MM helped in learning science:

> *It was fun so I paid more attention.*
> *I think it helped me because you kept having to think back on it and write and draw so you remember it better.*
> *Yes, I think it helps a lot. You can see it and it is less confusing than words.*
> *It was more interesting than usual. It was easier to read. Usually we just read paragraphs.*
> *MM helps me understand my own information.*

As mentioned previously, some students did not feel that the MM tool helped in their learning of science. When probed about their reasons for these beliefs, they reflected ambivalence about using the tool rather than an acknowledgement that the MM tool was not effective in any manner. One girl enjoyed using MM, but reported that she "learned the material faster if [she] just read about it." She continued to elaborate, stating, "It is much easier for me to express myself with words than with pictures." Two students felt MM was confusing in both the construction and interpretation of the maps, but believed the maps did give them some information and opportunity for learning.

As pointed out in the previous section, mind maps were used in a variety of ways by students and for varying purposes. Student-generated maps were both individual and the result of group collaboration. Most students enjoyed creating mind maps both individually and in a group context; however, other students reported preferred conditions for using mind maps. Some preferred individual MM to group mind map creation because it did not require negotiation within a group and allowed the expression of more individual ideas. This is evidenced in comments such as: "I would rather work alone because I tend to want to use my own ideas. If I have to work with others, I can deal with it," "I can concentrate better [alone] and I like not having to split up the work," " You do not have to listen to what others think and you can be as creative as you like," "Group maps are ok, but I don't like having to compromise my ideas."

When students preferred group MM to individual MM, they attributed the preferences to group work being more fun, the opportunity to learn more from others, and the ability to work more productively. "Everyone helps out so it went faster and there was more information," "Sometimes it can be frustrating working in a group, but it is better with different people," and "Yes, it was fun working with different people."

Although Robin and Karen did not continue the study formally into the second year (Karen relocated to a university in another country), they collected some followup data from the students, now in grade seven, and continued to collaborate. "I asked for feedback about mind mapping from my last year's grade 6 students who had been the subjects in our research. I used a simple questionnaire. Their responses were somewhat disheartening even if expected" (Robin) In 95% of the cases, students reported that they had not used mind mapping in any form since her classes the previous year. Many of them did report they believed that it helped them organize their ideas and was creative. All reported their reason for non-use was due to a lack of teacher suggestion and/or that they had simply forgotten about the process. However, as they did not expect teachers to ask them for it in the future, few doubted that they would ever use it again.

Teacher perceptions of mind mapping. [1] As a teacher, I have found that too frequently I share information with students via an extended participatory model, i.e. directed note-taking, open ended questioning and modelling, only to find out a week later that they really did not grasp the focus of my lesson. Mind mapping provided a unique window into my students' struggles in this area. While all of them had experiences with a range of graphic organizers, none had previously been exposed to mind mapping. For the most part, they were excited by the opportunity to use colour, symbols and generally expand their ideas in such an open format. In class, we made several group mind maps in preparation for the hallway class mind map on Antarctica. Additionally, they completed several individual ones both as homework and in class. Nonetheless, after a week of research when they returned to contribute their material to the class mind map, many of them began to lean heavily on text, with the symbols functioning as elaborative decoration.

For me, this was somewhat frustrating until I reflected upon my own experiences in learning the process. Certainly, making my initial maps with Karen and looking at examples in text, the process seemed straightforward. However, mind mapping requires a subtle interplay between text and graphics that is cognitively demanding. To use a light bulb symbol with "new" beneath it to denote a new idea is a fairly easy task, but to explain the difference between zooplankton, phytoplankton and plankton using symbols and key words is more demanding.

So, in teaching mind mapping as a skill, I found myself looking at other areas in my curriculum where I have probably made the same mistake, assuming that I had done a thorough job of presenting a new concept. The more one teaches, the easier it is to forget just what students really find new and difficult. The old ideas become so much a part of veteran teachers' instructional menus that they can easily can forget for students, they are a new experience. Thus, a natural by-product of introducing mind mapping was energized self-reflection on other areas of my instruction.

When students successfully completed a mind map and I had the opportunity to discuss their work with them, it was clear that most had made meaningful use of the tool. Moreover, those students who routinely struggled with expository expression had clearly gained self-confidence from being able to explain their science understanding in this new, less text-based format. As a result, overall I found that it was a valuable tool and well worth the time given to teaching it as a skill.

Aside from the value I saw in mind mapping as an individual tool, the large group mind map was a great whole-class activity. All students enjoyed watching the map grow and a many members of the school community stopped to read through portions of it. This latter action was noted far more often than when standard papers, charts or reports were posted in the same location. Thus, it served both as a way to help students bring together a large body of information, as well as a way to highlight their achievements.

During the 2001-2002 year, I have undertaken several efforts to interest other teachers in adopting mind mapping as a tool in the belief that such skills are most successful when reinforced beyond an individual classroom. I knew better than to suggest a faculty meeting for a presentation of this tool because time for curricular innovations is scant and without a grass roots demand for such a meeting it would possibly cause resentment. Our independent school faculty is a very creative group, having many more exciting and unusual ideas than could ever be studied and/or shared during the entirety of a school year. Therefore, I hoped to generate interest in mind mapping as part of a middle school project to share and adopt each other's learning tools. This idea was received enthusiastically and a committee

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[1] This section and the subsequent section is written by Robin and her voice is used to communicate her unique perspective as a teacher researcher.

was formed, but at this writing, two months later, the committee has not yet convened.

I will continue to search in my local school community for others who might make room for MM in their notebook of possible methodologies and present it at science workshops with the hope that in a larger arena, there will be more interest. I also have the possibility of introducing it to grade 4 students whom I teach on a weekly basis. This would mean that the process could be modelled and used by Pinegrove students for three years during science classes with a far better long term result – and the possibility of another research project. In truth, were it not for the research tie-in to my introduction of mind mapping which has forced me to critique it in depth, I suspect that I would have let it move to the back burner with so many other innovative ideas that I have tried over the decades. In the end, perhaps the greatest gain I have received in undertaking the mind mapping research is a renewed energy to incorporate it more successfully into my curriculum.

Implications for Science Teaching and Learning

In this study, MM was using by the teacher as both a teaching and learning tool. Robin used the tool to generate teacher-created maps during direct instruction, explaining ideas and concepts. In addition, MM was used by students to consolidate and record their developing understanding of concepts and ideas through both individual mind maps as well as group-generated mind maps. MM has considerable flexibility as both a teaching and learning tool. However, as with any instructional strategy, teachers need to be cognizant of the purposes for using a particular strategy and the outcomes they hope to achieve when adopting it. In addition to flexibility in application, MM may be combined with other approaches such as cooperative learning, on-line learning, and computer-assisted learning. For example, MM was integrated with the on-line component of the *Blue Ice* unit, using many of the suggested sites to gather information and then transfer this learning into the creation of the whole-class mind map. Although not used explicitly in this study, computer software such as Inspiration (2000) and other mapping programs could provide another tool for exploring MM.

The MM tool fostered student motivation in learning science. Although at times the students were required to address specific concepts and ideas in their mind maps, there was considerable leeway for students to express their individuality in their maps. The creative components of MM–using it as a brainstorming tool, incorporating colour, symbols, and pictures, and expressing ideas and connections amongst ideas in unique configurations–seemed to be an aspect of MM that contributed to their positive attitudes about MM.

As noted previously, some students did not enjoy the MM tool because it they found interpreting mind maps confusing, or the creation of mind maps did not meet students' preferred learning styles. This supports the notion and is consistent with the prevalent theme that science should be accessible to all students (American Association for the Advancement of Science (AAAS), 1989, 1993; National Research Council, 1996), regardless of their race, gender, socioeconomic status, culture, ability, or interests. If teachers are to reach all students in the regular classroom, they will need to adopt eclectic teaching and learning approaches and strategies that will cater to the needs of diverse learners. Students will be better equipped if they have a diverse repertoire of learning strategies that allow them to explore ideas and consolidate their developing understanding. Helping students develop facility with a new learning tool offers them more variety in how they can learn and be assessed. Yet, not all students in the study liked the MM tool, while others were ambivalent about its use. A particular approach to learning will not appeal to all students; thus, the adoption of a variety of instructional and learning strategies would be more likely to cater to multiple intelligences (Gardner, 1983, 1999) and students' diverse learning needs.

Although the positive learning outcomes, affective and cognitive, that were reported by students in this study cannot be attributed solely to MM (many other constructivist-based learning approaches were adopted in the inquiry), MM certainly contributed to the overall success of the *Blue Ice* unit.

Concluding Comments

Many teachers strive to find ways to make the learning of science more meaningful for students. Like other graphic organizers, mind mapping has the potential to foster symbiosis in learning (Novak & Gowin, 1984), helping both teachers and students "penetrate structure and meaning of the knowledge they seek to understand" (p. 1). This study was an attempt to explore the use of a learning tool, MM, and its potential for enhancing students' ability to engage in the learning of science. Although small in scale, it does provide some preliminary evidence for the value of MM. Students were able to understand the nature and purposes of MM and most mastered the skill in a relatively short period of time. The majority of students liked using the MM tool and identified several ways it enhanced their learning in science.

The above experiences also suggest that MM will only find a foothold in classrooms when it is reinforced either longitudinally year-to-year, and horizontally across grade-level curricula. Used in isolation in one classroom, there appear to be benefits for that current year, but the lasting benefits are unclear.

More research is needed in the context of K-12 science and technology to determine the effectiveness of MM as a teaching and learning tool. Some research questions the authors would like to pursue further include: Is the technique suitable for older and younger learners? Is it more effective as an embedded assessment tool as opposed to being a summative assessment tool? Does the technique have the potential to enhance writing in science? These are but a few of the questions that warrant further research.

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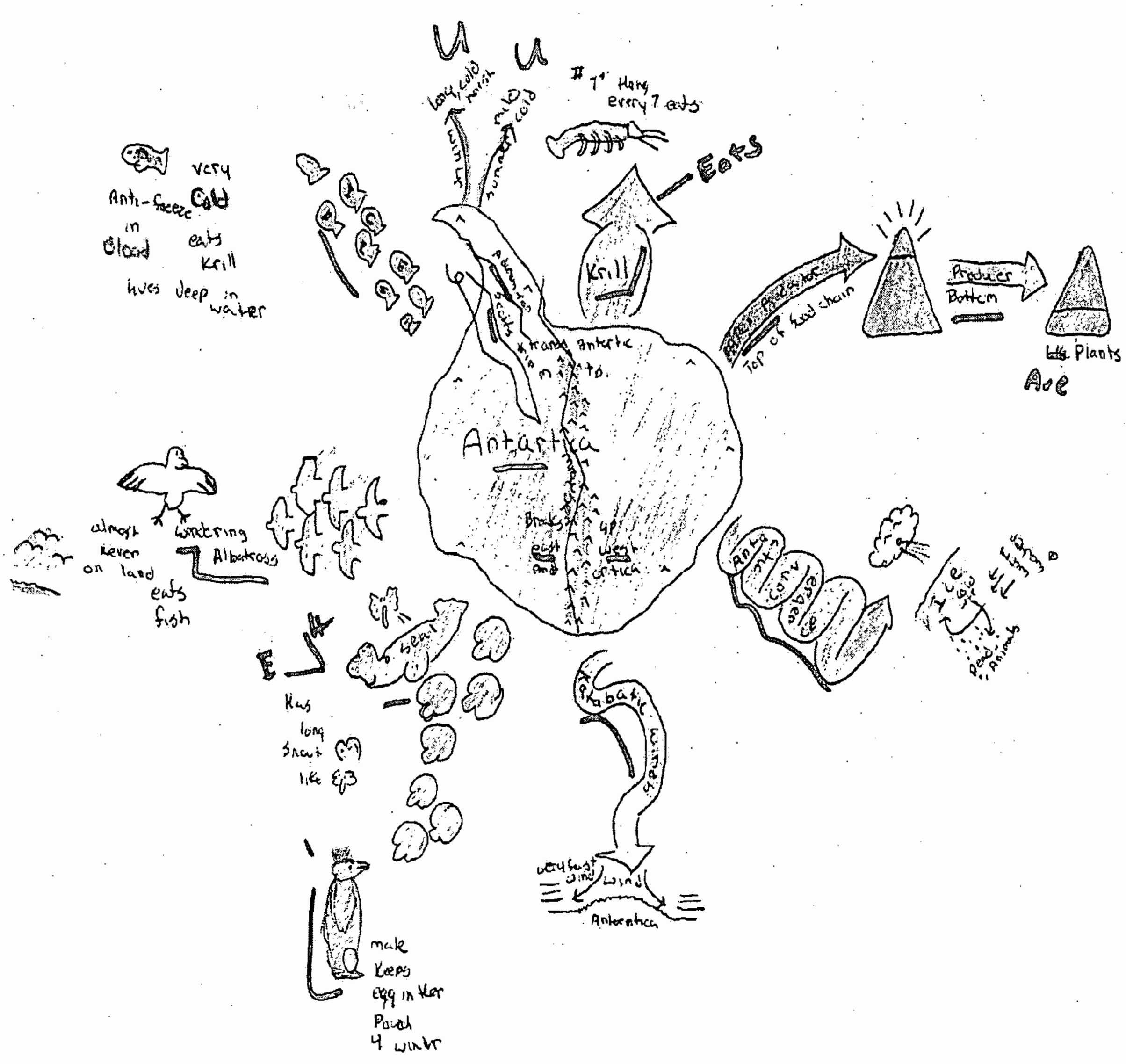
Appendix A
A student-generated mind map completed as a culminating assessment at the end of the *Blue Ice* unit.



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Appendix B
Learning goals, assessment, and learning activities used in the *Blue Ice* unit.

Learning Goal	Student Assessment	Learning Activity
To broaden students' knowledge of basic geography and climate of the Antarctica	Informal assessment.	Complete in a partially completed map using designated Internet sites.
To help students become more familiar with the climate of and the physical location of the continent	Individual homework assignment about a trip to the Antarctica. These were later published at the on-line *Blue Ice* site.	Students generate a list of items they will need to travel to the Antarctica. They are expected to defend their choices.
To develop an in-depth understanding of the Antarctica ecosystem	Grades are assigned individually and as part of a team for work completed for each item.	In teams, research four Antarctica organisms. Find and read Internet resources and information. Complete a research sheet about each organism Prepare a model of one of the organisms. Make a 8x11 inch mind map of information researched. Complete a portion of the large class mind map. Maintain a notebook of all work.
To reinforce information gathered through reading text.	Homework: In an essay, discuss the adaptations of penguins that allow them to survive in the Antarctica environment.	Viewing of videos.
To provide practice with basic laboratory skills. To elaborate on concepts introduced earlier in the unit.	Individual laboratory reports.	Four learning stations: investigating food chains, using mapping skills, experimenting with temperature and hand coordination, and comparing caloric needs of an Antarctica traveller and a grade six student (normal living)
To increase students' appreciation for the variety of life forms that are part of the Antarctica ecosystem	Informal observation	Looping game
To increase students' appreciation for the nature of the Antarctica environment and human's need to explore.	Class discussion (informal)	Reading of an account of an expedition to Antarctica (Mawson expedition)

To assess students' overall learning in the unit.	**Holistic rubric used.**	**Using key words from the unit, students create a mind map that reveals their understanding of key concepts and the relationships amongst the concepts.**

Appendix C

Survey and Interview questions used at the end of the study to assist in exploring students' perceptions of mind mapping as a learning tool in science[2]

Part A: Please read each of the following statements about mind mapping carefully. Circle the answer that best reflects how you feel about the statement.

- It is difficult to create map.

Strongly Agree Agree Disagree Strongly Disagree Not Certain

- Mind maps help me organize my thoughts.

Strongly Agree Agree Disagree Strongly Disagree Not Certain

- I enjoy creating mind maps.

Strongly Agree Agree Disagree Strongly Disagree Not Certain

- Creating a class mind map was a boring experience.

Strongly Agree Agree Disagree Strongly Disagree Not Certain

- Mind mapping helps me understand concepts and ideas.

Strongly Agree Agree Disagree Strongly Disagree Not Certain

- Mind mapping allows me to be creative.

Strongly Agree Agree Disagree Strongly Disagree Not Certain

- Creation of a class mind map helped me understand the relationship between the animal I researched and its environment.

Strongly Agree Agree Disagree Strongly Disagree Not Certain

Part B: Please read each question carefully. Write your response in the space provided after each item.

1. What are the important parts of a mind map?
2. What is the purpose of mind mapping?
3. Did the use of mind mapping help you in learning science? Explain your answer.
4. What did you like about mind mapping?
5. What did you dislike about mind mapping?
6. Did you enjoy creating the class mind map from the *Blue Ice* unit? Why or why not?
7. Do you like creating group mind maps?
8. Do you like creating individual mind maps? Explain your answer.

[2] Part B questions were completed as part of the survey, but also used during student interviews.

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